SPIE PAPER NUMBER: 9739-28

AlGaInN laser diode technology for free-space and plastic optical fibre telecom applications

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PACS: 42.55.Px; 42.60.By

Keywords: GaN laser, GaN array, free-space communication,

Abstract

Gallium Nitride laser diodes fabricated from the AlGaInN material system is an emerging technology for laser sources from the u.v. to visible and is a potential key enabler for new system applications such as free-space (underwater & air bourne links) and plastic optical fibre telecommunications. We measure visible light (free-space and underwater) communications at high frequency (up to 2.5 Gbit/s) and in plastic optical fibre (POF) using a directly modulated GaN laser diode.

Results

The lack of a suitable low defectivity and uniform GaN substrate has been one of the limiting factors for GaN laser diode technology. Recently, single crystal growth of large area, very low dislocation density and uniform GaN substrates are grown using a combination of high temperature and high pressure has been realised, enabling a range of AlGaInN laser technology to be developed [1,2].

A typical AlGaInN laser diode epitaxy structure grown by MOCVD consists of; i) 0.8 μm $Al_{0.08}Ga_{0.92}N$ lower cladding layer, ii) 50 nm GaN lower waveguide layer, iii) 50 nm $In_{0.02}Ga_{0.98}N$ injection layer, iv) $In_xGa_{1-x}N/In_{0.02}Ga_{0.98}N$ quantum wells x3 (3.5/9 Å) - the indium composition x (x=0.05-0.2) and well thickness can be varied to change the emission wavelength, v) 20 nm $Al_{0.2}Ga_{0.8}N$ Electron Blocking Layer, vi) 80 nm GaN waveguide and vii) 350 nm $Al_{0.08}Ga_{0.92}N$ upper cladding. All of the data presented in this paper are for AlGaInN laser diodes grown on the c-plane of the Wurtzite crystal.

AlGaInN epitaxy structures are processed into ridge waveguide LD's, with a typical mesa etch depth of 420 nm, cavity length of 700 μm and a stripe width varying from 3 to 10 μm. After cleavage, the LD's are HR coated (5x ZrO_2/SiO_2 quarter-wavelength layers) with 95% reflectivity and AR coated with 10% reflectivity. Devices are mounted p-side up on in TO5.6mm or TO9mm packages.

The LIV and the beam profile characteristics for a 2μm ridge waveguide LD structure packaged in a TO5.6mm package are shown in figure 1a). The device has a threshold current of ~65mA, with a threshold voltage of ~5 V, a lasing wavelength of 410nm, and a characteristic temperature T_0 of ~120 K. A single transverse mode optical beam profile is observed in both the slow and fast axis with this device (see fig.1 b).

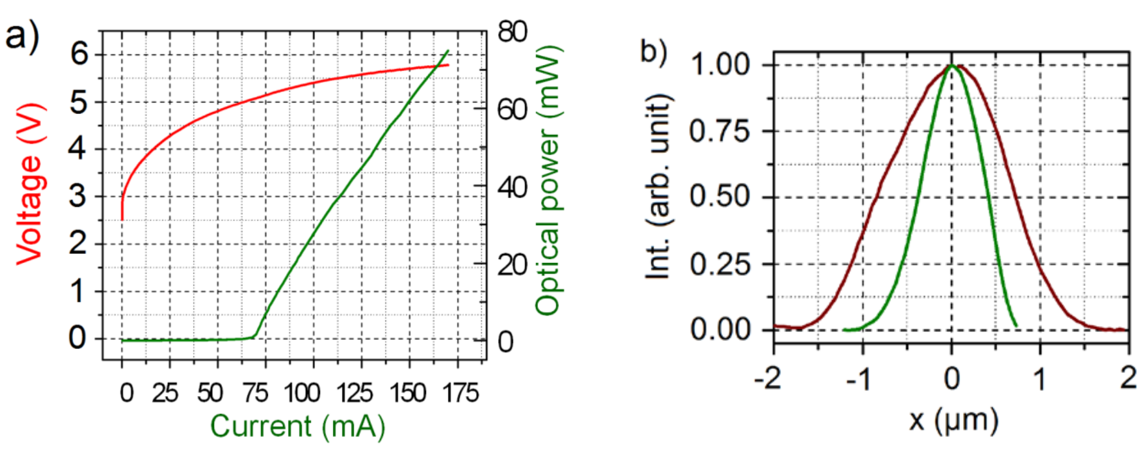

Fig.1 AlGaInN 410nm laser diode characteristics, a) LIV , b) Near-Field (slow axis – red line, fast axis – green line).

High resolution spectral measurements of the AlGaInN LD's reveal fine mode structure with a characteristic dominant single longitudinal mode more reminiscent of a DFB type of laser device with etched grating, providing optical feedback for mode selection, rather than a more standard 'mode comb' Fabry-Perot device with no etch grating. The single mode characteristics of a ~422nm GaN laser diode is measured at 24mW operation , a dominant single longitudinal mode at 421.6nm, with multiple small side modes is observed (see left hand side of figure 2). Similar single longitudinal mode characteristics has also been observed in the spectral output of other AlGaInN laser diodes and was explained by surface roughness inadvertently introduced during growth [3] and that the single mode is stabalised by longitudinal mode competition caused by optical gain saturation [4]. Similarly we observe a surface topology of the order of ~10nm in height and a periodicity of 100nm [5], eventhough the epitaxy growth is done on very low defectivity ($<5x10^4cm^{-2}$) GaN substrates with a flatness of <0.1nm [6], the surface topology features appear inadvertantly in the last epitaxy layer of growth.

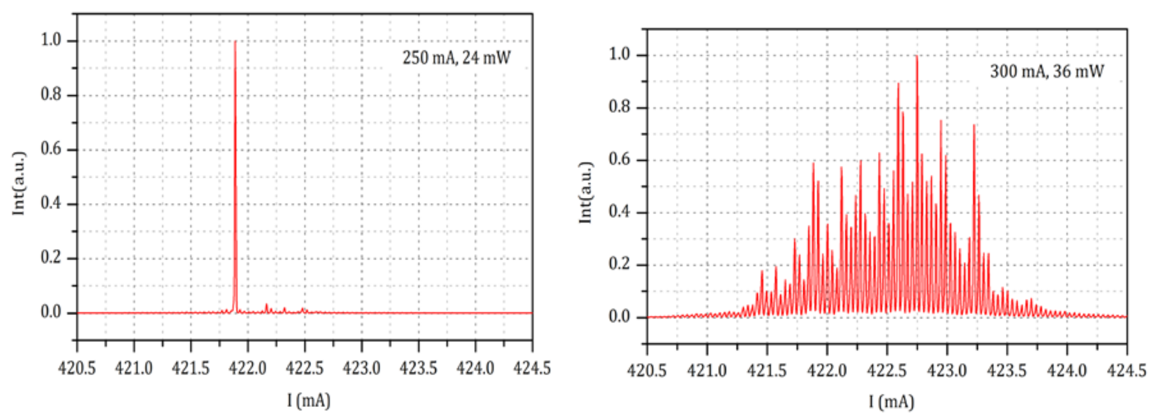

Fig 2 The evolving spectra of a ~422nm GaN LD's vs increasing drive current mA/optical power mW (cw) at 20^0C

The dominant single mode characteristic is observe in all our AlGaInN LD devices at moderate optical powers up to ~25mW. At a higher optical power (36mW), the single longitudinal mode jumps to a spectrally wide (~1-2nm) mode comb as is more typical of a Fabry-Perot LD device (see right hand side of figure.2).

The narrow linewidths of the GaN laser diode shows the potential of the technology for telecommunication applications (as well as other applications that require very narrow linewidths, such as atomic clocks). In addition, the wavelength tunability of the AlGaInN system allows nitride laser diodes to be tuned to specific telecom applications, such as free-space, high speed data transmission at a Fraunhofer line, e.g., 422nm, for a low solar background to underwater. Or for more borad-band telecom applications such as wavelength multiplexing in plastic optical fibre.

Free space data transmission measurements were carried out using GaN blue laser diodes. Eye diagrams, measured using an Agilent 86105B digital sampling oscilloscope (DCA), are shown in figure 3. High frequency data transmission at 1.1 Gbit/s was measured for a laser drive current of 115mA and 2.5Gbit/s for 120mA, at which the best Q factor margins are achieved [7].

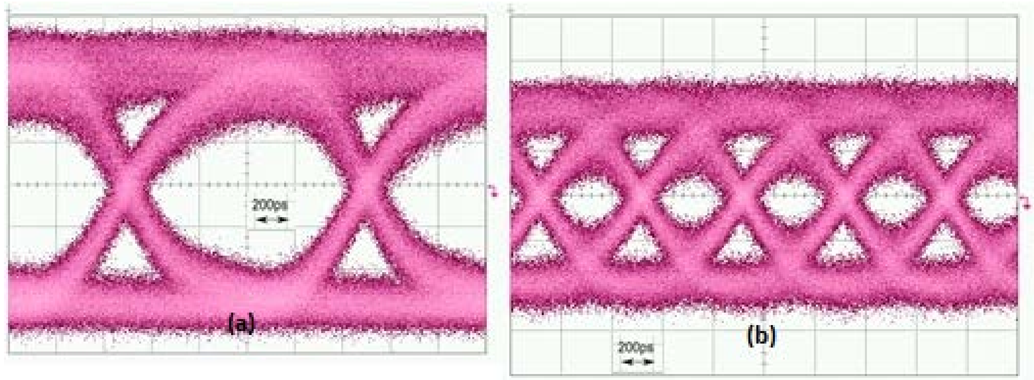

Figure 3. Eye diagrams at (a) 1 Gbit/s and (b) 2.5 Gbit/s at photo-receiver output.

To test the suitability of GaN laser diode technology for under water communications, a GaN laser optical tracking system was constructed and submerged in a water tank and its performance was determined as the water conditions were varied by introducing Maalox which mimics the volume scattering of seawater particles and is commonly used in underwater light-scattering experiments. Several GaN laser diodes were tested over a short underwater path length of 1 metre with their centre wavelength in the range of 421nm to 425nm (see figure 4 below). These wavelengths are in the range corresponding to lowest attenuation for optical wavelengths in waters classed as ‘oceanic clear’, whereas with increasing turbidity the lowest attenuation shifts to longer wavelengths.

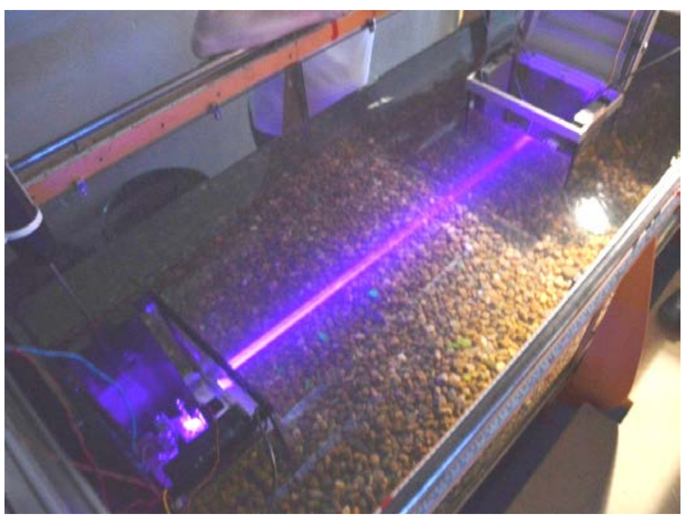

Figure 4.: Collimated laser fired underwater from node to node in harbour type water, over a 1 m distance.

High-frequency data transmission under water at similar Gbit/s rates has also been measured using a 422nm GaN laser diode (see figure 5) demonstrating the suitability of GaN system technology for underwater sensing and communications [8,9].

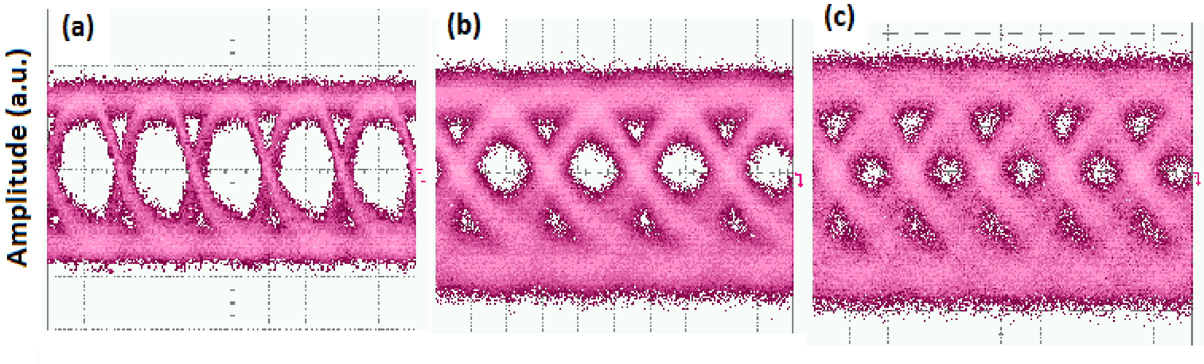

Figure 5: Eye diagrams showing data transmission for a signal transmitted through water at (a) 1 Gbit/s at 125 mA drive current, (b) 2 Gbit/s at 132 mA and (c) 2.488 Gbit/s at 132 mA.

The above GHz free-space and underwater data transmission results show the potential of AlGaInN laser diodes for use in plastic optical fibre (POF). High speed measurements were conducted through varying lengths of 1mm diameter step-index plastic optical fiber (SI-POF). A 429nm laser diode was used to conduct frequency response measurements through the fiber lengths of 1 m, 2.5 m, 5 m and 10 m versus bandwidth. This device had a -3 dB bandwidth of 1.71 GHz in free space and could achieve error-free data transmission at 2.5 Gbit/s, in a similar manner as reported above. The maximum bandwidth values achieved for transmission through 1 m, 2.5 m, 5 m and 10 m of fiber were 1.68 GHz, 1.63 GHz, 1.62 GHz, and 1.1 GHz, respectively (see figure 6).

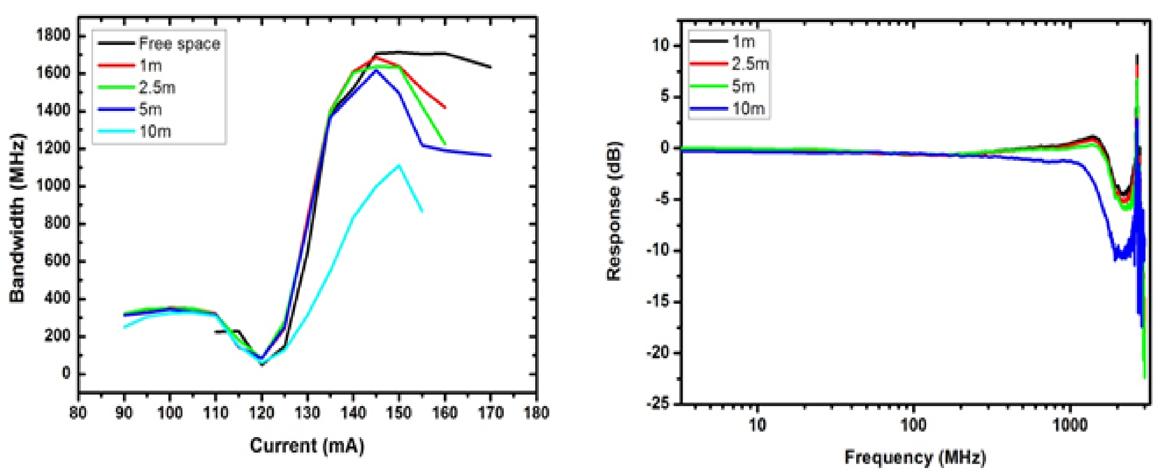

Figure 6: (a) Current vs bandwidth for varying lengths of SI-POF and (b) Fiber response as a function of length.

CONCLUSIONS

GaN laser technology has the potential for a compact, very high data rate (GHz) source for novel telecommunication applications such as underwater optical communications and plastic optical fibre. We measure blue light (free-space and underwater) communications at high frequency (up to ~2.5 Gbit/s) using a directly modulated 422nm Gallium-nitride (GaN) blue laser diodes and GHz data transmission over plastic optical fibre.

Acknowledgements:

This research has been supported by the European Union with grant E!9776 and the National Centre for Research and Development within the project E!9776/NCBiR/2015.

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